Minerals and Man

By

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Dean of the School of mines, Columbia University;

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I. Ancient Man and Minerals.

When we talk about "ancient" man we must not forget that actually we are talking about beings that are really very recent comers to our world. If we estimate the length of time our world has been in existence as 10,000 million years, we find geologists, with their guesses as to how long it took animal and plant types to evolve, chemists with their calculations as to the rate at which radium disintegrates, and astronomers with their computations upon the phenomena they observe all in substantial agreement that that is somewhere about the right length of time. Now take the last one per cent of that period, 100 million years, and then the last one percent again, or 0.01 per cent of the total length of time, as the only part of it in which we are sure anything like man existed, since there is still much dispute as to whether the earliest remains we find are those of man-like apes or of ape-like men, as well as to exactly how old they are. It is only in the last ten per cent of the last of the 10,000 million years, or 100,000 years that we know anything to speak of in regarding man in his relation to minerals.

All we can possibly know concerning that early period is what still remains of it. We find the caves in the rock in which ancient man sheltered himself, the rock surfaces on which he tried his hand in attempts at pictorial art, the stones he piled up to make himself a better fireplace, those that he hollowed out to make a mill in which to grind his food and the pestles with which he ground it, the stone heads of clubs and primitive axes, and the arrow heads he fashioned from stone to help him capture his game for food. In the

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*A series of three lectures delivered by Professor Thomas T. Read before the mining and metallurgical engineering students of Peiyang University from September 23 to 25 ,1936, on his coming back visit to Peiyang after he left here for 26 years.

begining he simply picked up stones of a size and shape that suited his purpose, but these were naturally scarce and very early we find him doing things to the stones to modify them to fit his purpose; the beginnings of technical skill. It is very easy to over-estimate the skill that he developed, and it is very commonly done, especially in the case of arrow-heads. Provide an ordinary boy who possesses any skill in the use of his hands with the right material to work with and somebody to show him how to set about it and he can usually learn in one afternoon how to make arrow-heads as good as the best that ancient men ever made. One of the most important things was to secure the right material, flint, to work upon.

Flint, like other minerals, was first picked up from the surface, and then they began to dig them out of the ground, and we have the beginnings of mining. Of course there is always the dispute whether holes dug in the surface are mines, because the name of quarry has been attached to such excavations, and only holes in which you get down underneath the surface are sometimes considered to be real mines. But I think that in this, as in law, it is the intent that matters, and if men dig in the earth intending to use the mineral they take out they are mining, as contrasted with digging a canal or the foundation for a building. This primitive mining must have begun very early in our 100,000 year period, for as long ago as 20,000 or 30,000 years they had gone down under the surface and were digging out sideways in a favorable bed; that is, they were really mining.

This period of time in the history of man is known as the Stone Age, and the implication is that men then used only stones, not metals. This must surely be wrong, for gold, except for a few rare places in the world, is found only in lumps of metal that must surely have attracted the attention of men who were hunting in stream-beds for stones to suit their purposes. No mineral is more highly prized than this, though very likely early men were not as delighted as those of today when they found gold, for you must remember that gold is really one of the most useless of metals, and the only one that, except as jewelry and to a limited extent in chemistry, serves man's purposes by merely exsisting. There is something almost absurd in the great effort with which we dig gold out of a hole on the ground, cast in bars, and then put it in another

hole in the ground where it remains undisturbed from year to year.

But gold had an interest for primitive man, aside from its color, because it was soft and he could easily change it from the shape in which he found it to one more pleasing to him, and so the art of metal-working was born. He not ony found gold but also a redder and slightly harder metal, copper, and also, more rarely, a white one, silver. And to his great delight he found these last two in larger pieces than he did gold, and consequently could do more with them. Copper was the only one that was abundant enough to be much used in any practical way for the making of things for use, as distinguished from mere ornaments. The age of stone is ordinarily described as having been followed by the age of bronze, but actally men must have been making a limited use of copper, gold, and silver all through the stone age. On the other hand, many of the primitive objects to be seen in museums that are labeled bronze have been found by analysis to actually be native copper, and not bronze at all. The people of South America, for example, never made any true bronze but only fashioned metallic copper into articles of use.

One trouble with these metals was that although pieces large enough to be of use were sometimes found, it was very much easier to find small pieces especially of gold. More than half of the world's gold today is being obtained from ores in which no visible gold can be seen. But man had already learned a technique that would enable him to overcome this difficulty. Long before he had noticed that when clay is subjected to the action of fire it changes its character and alters from being soft and plastic into a hard and resistant form. This not only provided him with a new and much easier way of making the vessels he needed for domestic use, but gave him an important idea;--perhaps other things could be changed by the action of fire. He had learned to control the ate of burning of fire by controlling its draft, and now he learned something else important; how to make a hotter fire by forcing the draft. It was not such a difficult discovery, for one often sees a person today trying to make a fire burn better by blowing on it, so the blow-pipe is a natural development. The earliest evidence of its use that we have is in Egyptian bas-reliefs where workmen are shown using it to melt gold in small crucibles made of clay, but it was probably used long before the date of these pictures, which are perhaps

6000 years old.

When this method was used to convert little pieces of metal into lumps big enough to use the fused metal took the shape of its container, and another important new idea occurred—why not pour it out into something of the shape you wanted it to be, instead of working the lump into that shape, and thus save yourself much labor. So the art of mold-making and casting came into existence, and was very early perfected. I must digress here to point out to you that the idea that we are continually progressing is subject to the fact that when you have once found the right way to do what you want there is no more progress to be made, you simply keep on doing it in that same way. That is true of casting. Man soon developed an extraordinary degree of artistic skill in the making of molds ,and they have found in Sumer, for example, a little figure of a donkey, cast from gold, that was used as an ornament on a Queen's chariot, which for perfection of execution could not be excelled today. Perhaps you have seen some of the Shang Dynasty bronzes found at An-Yang and have noticed that they are quite as good as those made in later periods, but we have many castings much older than Shang times that are remarkably fine examples of metal-work.

Now we have a technique for the making of metal objects of any size and shape desired, but the supply of metal was still rather short. Literature is full of fanciful hypotheses as to how smelting,—the making of metal from that which is not metal—came to develope, and it is curious that among so many the most probable never appears. The stories of a shepherd sitting over his fire and noticing metal trickling from the stones he had placed around it, or of hunters wandering through a burned forest and noticing metal reduced by the heat are utterly impossible. If such things happened, which is implausible in itself, the observation would have no significance to such men; what would drops of metal mean to a shepherd? The man who first discovered that fire would convert that which was not metal into metal must have been a worker with fire and metal, in other words, a caster. In picking out pieces of copper to melt it was difficult to completely free it from adhering mineral, and not necessary, because the heat would melt it away. Some observant melter would notice that the mineral was changed by the fire, and that he had more copper

at the end than he started with. Or he might, in an idle moment, have tried what the fire would do to the mineral associated with the copper, and be rewarded by obtaining metal from it.

Again I must digress to observe how fortunate it was for the workers that some metals, notably copper and lead, commonly occur in nature as mixtures of oxides and sulphides. All you have to do is to heat them, and the sulphur and oxgen react, producing metal. And all that is necessary with tin ore is to put a little charcoal, or other reducing agent, in with it and you easily obtain the metal. From these easy operations the metal worker progressed to more difficult ones, such as the preliminary roasting of sulphides, so they could be reduced by charcoal and the mixing of ores, so that the resulting metal would have the qualities desired.

Out of this came the making of bronze, which was so extensively used that it gave its name to an Age in history. The metal-worker had much difficulty with the melting of copper, because a little of the oxide is quite soluble in the metal and makes it too brittle for subsequent working. But if there is a little tin in the ore mixture the resulting metal not only is sounder and freer of flaws but is harder, and can be made still harder by hammering it. In this way knives, swords, and other cutting tools could be made with quite sharp edges which had always been a difficulty before. From the smelting of copper ore that accidentally had tin in it, the smelter progressed to the mixing of tin ores with those of copper in the proportion that yielded the best metal. Probably a very long time passed before the present method of making bronze by first making copper and tin and then melting them together was developed. I must refer here to another popular delusion; that the ancients knew how to "temper" copper, a secret that has since been lost. This is a double error, for temper actually to soften something that is too hard, and what the people who talk in this misguided way actually mean is to harden copper so it will be hard enough to cut. Practically anything you put into copper hardens it, it is the easiest thing in the world to do, but unfortunately it also makes it too brittle for use. What the ancients used to do was to treat the edge of a copper tool with antimony, which if skillfully done gave it a razor-like but very brittle edge. We can do that today but nobody wants to. The periodic announce-

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ment in the newspapers that some ignorant person has discovered how to temper copper is completely foolish.

This matter of maintaining a sharp cutting edge had always been troublesome, anything that was hard enough to stay sharp was so brittle it would chip off. What was needed was something both hard and tough; bronze was the best appoximation, but no amount of hammering would make it hard enough. The Egyptians had to do their stone carving with copper chisels, that they resharpened after every second or third blow. That was not practicable in fighting, and swords were made of bronze.

For centuries the metal workers had been fooling with a difficult metal that they could do almost nothing, though we now find it the most useful of all—iron. The trouble was that although they could reduce it from its oxide ore quite easily, what they obtained was a spongy soft mass; they could not melt it. By hammering it while hot they could compact it into a solid lump, but it was too soft,—softer even than copper. Eventully some persistent worker noticed that if you had heated it while buried in charcoal and then plunged it into water it became hard; and thus one the most important—perhaps the very most important—the heat treament of metal to harden it, was made. Almost two thousand years passed before men learned how to heat treat other metals and alloys.

There is another popular delusion here. You will find literature full of statements to the effect that iron appeared so late because furnaces had not been perfected to the point where a high enough temperature could be obtained to reduce it. That results from ignorantly supposing that the ancients made iron in the same way that we now do, which was not at all the case. The temperature required to reduce iron from its oxide is quite low,-well below that necessary to melt copper or bronze. The real point is that temperature alone will not reduce iron oxide, you have to have a large excess of fuel present so the carbon dioxide produed by the reaction never gets above a low concentration, otherwise the metallic iron goes back to oxide. It took a long while to find that out, as you can well imagine since the primitive worker had not the faintest notion that the mineral substances he was working with were compounds, nor any way of analysisng them to find out what elements were present.

As late as Roman times people supposed tin was merely a white variety of lead, while the same word was used indiscriminately for copper and bronze. Nobody knew there was such a thing as zinc, though they were using its ores to turn copper into brass, which they did not recognize as an alloy, supposing a special variety of copper. I believe that when men found they could produce metal from that which was not metal they tried every mineral to see what they could get from it. Iron oxides are among the commonest and most noticeable of minerals, they must surely have tried them, and produced some soft spongy iron, but it was hundreds, almost thousands of years before they learned to harden it enough to make it useful. It took a long time more to perfect that process, and in old Sagas you can read of warriors fighting with iron swords that bent when they struck with them, so they had to stop and step on them to straighten them out. It was not good form to strike your adversary while he was straightening his sword!

Everywhere in the world except in China men made iron in the same way. They mixed the ores with charcoal, heated them, and got a soft spongy mass. They heated and hammered this until it welded into a solid lump, and then they hammered it into the shape they wanted it to be and then hardened it by plunging it into water while hot. While they had been heating it, over and over again, since it cooled quickly in the small lumps they used, the iron had absorbed carbon from the fuel and thus acquired the property of hardening, but they did not know that and so were unable to control the amount of carbon absorbed. Thus they never know how hard it would be, but if they got it too hard they found they could "temper" it by heating it to a bright heat and then letting it cool down before plunging it into water. So much fuel and so much labor was required that the resulting metal was expensive; iron objects then cost much more than bronze ones, strange as that now seems. Except for swords, knives and other cutting tools it was but rarely used.

But in the part of China that was the center of its civilization, the bend of the Yellow river, it so happened that just above the iron ore there occurred a thick deposit of coal that happened to be free from sulphur, and it was also anthracite, it did not soften and break up when heated and thus block the draft. Europeans never learned how to use coal in iron making until late in

the 17th century, but the Chinese used it from the very first, perhaps early in the Chou dynasty, because they had the good luck to have the right kind of coal. Along with thier soft spony mass of iron they obatained many small pieces, just as every body else did. They tried melting them in a crucible and found that with coal as a fuel they could do it, so they began casting iron, probably at least two thousand years before the metal workers of the Western world did it in any extensive way. There is evidence that the Greeks made some iron castings as early as the Chinese did, but they were so expensive as compared with bronze that there was no reason for making them. In China cast iron was much cheaper than bronze and so was used for every purpose it would serve. A most important one was the making of plow shares. China's soil is typically free from stones, so the brittleness of the casting did not matter, and it had a good resistance to the abrasion of the sand. It was not much used for the casting of art objects, it was too common and cheap a metal for that. Nowhere else in the world was it common or cheap and hardened wrought iron was neither common nor cheap anywhere, not even in China, for the labor and skill required to produce it made it everywhere expensive.

That brings us down to the Middle Ages and the Revival of Learning in Europe the recognized metals by then were gold, silver, lead, copper, tin, iron and mercury. Metal workers were making alloys, like bronze and brass. without knowing that they were alloys. All metals were rather expensive, and compared to the present times, minerals were but little used. The Chinese were probably the most extensive metal and mineral using people of the world and they had at least two techniques, the casting of iron and the making of the "pai tung" alloy, that no other people had. But from then on they made but little advance, while in Europe a tremendous surge forward was about to start. The Chinese did not share in this, in spite of their contacts with Europe, until the late 19th Century.

II. Minerals in Modern Life.

Perhaps I should say medieval and modern life, for it was the revival of learning in Europe, and the development of the science of chemistry that grew out of it that was the basic cause of the tremendous advance in the

control over and the utilization of minerals to maintain and improve the conditions of human life that characterizes modern times. But it was some time before this important change showed any effect in the mineral field, and the most noticeable development came from the mechanical, not the chemical side.

The expansive force of steam had long been known, and many vain attempts to utilize it had been made. The first practical success came in connection with minerals. The tin mines of Cornwall were very wet, and the only known way of getting the water out of them was to use horses to haul it up in buckets. A practical way was devised for using steam to raise the plunger of a huge lump. The term horsepower as a measure of mechnical energy arose because the only practical way of expressing the capactiy of the new machine was to compare it with the number of horses it displaced. One improvement after another was made in the steam engine, and it quickly became a rival of water-power as a means of driving rotating machinery.

These new machines were at first made largely out of wood, but metal quickly took its place, and they all required coal to furnish the heat to generate the steam, so they greatly stimulated the use of minerals, especially iron and coal. It was not long before the construction of an engine that would run on rails was attempted, and eventually succeeded. Slabs of stone, and wooden beams were tried as rails, but they would not do. A rolled strip of wrought iron was nailed to the top of the wooden beams, but that was not satisfactory either; a steel rail was needed and steel was too expensive to use.

We must go back now and trace the developments in the iron industry that took place between the Middle Ages and the beginning of the 19th Century. In China nothing happened, but in Europe great progress was made. About the 14th Century the furnaces were increased in size so that, quite unintentionally, the ore was in contact with the fuel long enough so that it took up enough carbon to reduce the melting point of the iron sufficiently so that it would mell and run out of the furnace. This greatly cheapened the process and made iron available for casting. A couple of centuries later the way to use coal as a fuel in iron making was discovered, and this further cheapened it. Next a man named Cort found a cheap and easy way to make wrought iron from this cheap

fused iron. Up till then all of it had been made in the old expensive way from unfused metal. He also invented mechanical rolls to roll his iron out in strips and sheets, making them ever so much cheaper than they had been before. The cheaper metal, in more convenient form, greatly stimulated the invention of new and improved types of machinery. Cort never made any money or got any credit for his great achievements, but the next inventor got a great deal of praise.

By this time it was clearly understood that the fused metal that came from the iron furnace contained about 3½ % carbon, analytical methods having been in use for some years. It was also understood that Cort's process utilized oxide to take out this carbon, yielding soft pure iron. To make steel, that is iron with just enough carbon in it so it would harden, a difficult and expensive process of putting back just the right amount of carbon was followed and thus steel was still so expensive that it was only used in a limited way. Henry Bessemer reasoned that since carbon burns you ought to be able to blow air through the fused metal from the blast furnace and thus reduce its carbon content to what was needed for steel. He tried it, and (though he soon found it was easier to burn out all the carbon and then put back just what was required) he made a workable process out of it and for the first time produced cheap steel. He was lucky that the way of rolling it out into required shapes had already been worked out for him by Cort, and that a big use for his product, railroad rails, had already developed. He received great honors and made a lot of money, but though better educated he was no greater an inventor than Cort. The use of iron and of coal increased by leaps and bounds; during the middle of the 19th Century the production of coal doubled every ten years in the United States.

About 1860 a mineral substance that had always been known, but men had never learned to use, came into use with a bound, namely petroleum. Long before Roman times a few futile attempts had been made to burn it in lamps, but nobody knew that it was a mixture of substances, ranging from gases to solids, and that it had to be separated into definite fractions before it was practicable to use it. It seems strange now that it did not come into use earlier, for analytical methods had long been known, coal had been distilled to produce an oil for burning, and considerable quantities of petroleum had been obta-

ined in drilling wells for brine. When it did start it went ahead with a rush, and was soon one of the most important of mineral industries. It is now second only to coal, but that is because, much later, it was found that the gasoline fraction, (which at first was simply thrown away or burned up), could be used to drive automobiles. It also furnishes better lubricating oil for machinery than the vegetable and animal oils that were at first used for that purpose.

Cheap iron rolled into thin sheets brought new uses for tin and zinc, for it was found they could be applied in a thin coating to the iron, to protect it from rusting. Zinc-coated sheets for roofing and tin-coated sheets for the same purpose, and for tin-ware for household utnnsils, greatly increased their use. Lead found a big new use in the plumbing of houses. Copper did not at first share in this advance, perhaps it even lost a little ground, since it had been used for cooking utensils and now tinware took its place. About 1880 the experiments with electricity brought practical fruit; Edison combined the electric generator, wiring systems, and the electric light (all invented by other people) into a workable system for lighting houses and distributing power that was to revolutionize things. Miles of copper wire was needed for the new systems and the consumption of copper increased tremendously. (the telegraph and telephone did not at first affect copper because they began by using iron wires and only substituted copper later.) Zinc shared in this development, for a lot of brass was needed in connection with electrical work, especially in its early days.

From the earliest times men had used stone and brick to build his dwellings. To fill the chinks between stones and to stick the bricks together some plastic material that would harden was needed. For this purpose he used clay, and it served very well in a dry climate, but would not do in a rainy one. Asphalt was also used, but it softened when the temperature rose. Very early it was discovered that if limestone were burned and then mixed with water, and with sand, it would slowly become hard, and for centuries it was the standard mortar. But about a hundred years ago it was found that limestone and clay, if burned together and ground fine was stronger and better. Now twentyfive million tons of this portland cement, as it is called, is made in the United States alone yearly, and other countries are equal large producers of it. In its production in the U. S. some ten million tons of coal and five million barrels

of fuel oil are required. This brings up an important point; in modern mineral production one mineral is often used in producing another, such as coal, limestone and manganese in producing steel, and a host of other examples. There are many important minerals that the general public knows almost nothing about, for it never sees them, since they are used only in producing some finished product.

It also illustrates another important point; that we have gone a long way from primitive man, who picked up a stone suited to his purposes. Now we make mineral products that suit our purposes, and an immense amount of research goes into studying those purposes, analyzing the factors involved and devising ingenious processes for treating the natural substances so as to bring out the qualities desired and eliminate those not wanted.

Nowhere is this better illustrated than in the field of metallic alloys. Early man made alloys, without knowing that they were alloys, but he only produced a few; now we have so many that the present is sometimes called the age of alloys. When chemical analysis was supplemented by the use of high-powered microscopes to study the nature and structure of alloys it began to be possible to make them have exactly the qualities desired. The importance of extremely small quantities of either undesirable impurities or beneficial constituents was recognized, and thus could be controlled. Now we sometimes find, with help of the spectrograph, that it is a ten-thousanth of a percent of something nobody knew was present that is giving us trouble, or perhaps producing a desired effect. Steel alloys are the best known and there are many minerals; manganese, tungsten, chromium, vanadium, molybdenum, and lately nickel, find their principal use in the making of steel. They do various things to it, such as making it harder and tougher, more resistant to the effects of heat and acid attack, and lately in protecting it from corrosion. "Stainless" steel, as it is called, had its origin from an attempt to pruduce something that would stand the heat and corrosion inside a cannon barrel, next it was developed for making steel tools that would not rust, and then for the outside surfaces of buildings. Now, oddly enough, the chief interest in it is as a competitor with aluminum as a material that is light and at the same time strong; most of the new lightweight railroad trains are being built largely of it. This illustrates another point;

that when you bring out a new mineral product to serve some specific purpose you can never foresee what other uses it is going to have.

Aluminum is a mineral that is wholly modern, because it occurs naturally as oxides, and it holds on to the oxygen so firmly that neither heat nor carbon, nor both together will take it away. Finally an electrical process for producing the metal was devised, and it was made available to man, but it never can be very cheap because 25 times as many energy units as are requied in making iron are necessary for aluminum production. Aluminum is naturally soft and weak, and quite a long time passed before it was found possible to make it harder and stronger without making it too brittle, but now it is a competitor with the strong light steel alloys (aluminum is naturally light; these steel alloys are light only in the sense that they can be used in thin sections) and has found many other uses, so it is now one of the major metals.

It will be useful to digress for a moment to review the human purposes for which minerals have been used in modern times. The most important is as a source of power. Man supplemented his own energy with that of animals, of animals, of the wind, and by water-power, but all these were of limited service. It is doubtful, for example, whether a water buffalo is really much use to a Chinese farmer; he costs about as much to maintain as the good he does. But two pounds of coal properly utilized, will do the work that a man can do in a day. and in modern mechanized American mines one man underground produces 30,000 pounds of coal in a day. Mineral fuel not only enables men to do many times more work (that done in the United States is about 35 times as much as could be done by its people unaided by fuel) but enables them to do things that they could not otherwise possibly do. For example gasoline enables men to fly through the air in airplanes.

Another thing that men needed was to move faster from place to place. Until the last century, except on ships, the best he could do was about 30 miles in a day except for short distances and periods of time. The development of the railroad made it possible to average 30 miles an hour for 84 hours in crossing the United States, and airplanes can fly at the rate of over 200 miles an hour. The other day I flew from Sianfu to Chengtu in three hours; a trip that would probably have required nearly a month on mule-back. Both

the railroad and airplanes are wholly mineral devices.

The quick transmission of messages was another enduring need. First the telephone and then the telegraph made it possible to transmit them almost instantly. The telephone was first only good for short distances, but now we can talk half-way around the world. Oddly enough, men invented the telephone was not trying to transmit messages, but to make it possible for deaf people to hear.

Men could only see what was in front of them while it was there; attempts to preserve the image gave us photography. Now we can see things that happened before we were born in places where we have never been. The research work done on telephones and photography finally gave us the talking moving picture and will perhaps eventually give us television. None of this could have been done without minerals.

Man was long subject to his environment; if the air was cold he was uncomfortable, when it grew dark he could not see. He early found a way to use fuel to warm himself and means of making a light. At first he used vegetable substances, but now we use only minerals for those purposes and accomplish them so perfectly that in an air-conditioned railroad train we can travel through a hot dusty desert in cool dustless comfort. Electric light not only makes the night as bright as day, but permits many effects not possible with sunlight, we can produce light of any color and intensity.

Minerals make it possible to preserve our food supplies indefinitly and to ship them long distances; the ordtnary man can now have things to eat that come from the ends of the earth. Only the Emperor of a hot country could have ice in the summer, now anybody can have all the ice they want in the tropics. I might go on indefinitely citing examples of how minerals have been used to improve the conditions of men's existence, and to permit them to do what they want to, but these examples must suffice. The minerals were always there, what man has done in modern times is to learn how to use them. He is still learning and will probably find many more ways in which they can serve him.

Of course all this has resulted in a tremendous increase in the rate of production and consumption of minerals. We have produced more of every

kind of mineral, even gold, since 1900 than was produced in all the time before that. The question at once arises as to whether we can indefinitely go on finding such large quantities of mineral. The known lead and zinc supplies of the United States will only last about 30 years at the present rate; petroleum maybe only half as long. Where are these minerals to be obtained?

First we must discuss the question as to whether we shall continue to require such large amounts. It has already been indicated that when petroleum gives out there are various things we can do. The world's caol supply is probably good for some 3000 years and long before then we may have found a way of obtaining energy direct from the sum, instead of second-hand from coal and petroleum. As to the major metals, we save them and use them over and over again, we can probably do a great deal better in conserving them than we have done while they are plentiful. I have already indicated that for many purposes several things are available; we use the one that is easiest and best. It will always be possible to use things that are less satisfactory, but more abundant. Altogether it does not seem necessary to be nervous about the future; the people living then will probably be intellingent enough to find a way.

We should also remember that so far we have penetrated only a short way into the earth. The deepest oil well, reabout 10,000 feet, only penetrates 0.04 per cent of the distance to the center. It is more difficult to work at such great depths than near the surface; but it can be done, though the problem of the heat at depth will be troublesome and possibly expansive. The digging of deep shafts has been expensive, but an American has recently invented a way of boring them that most probably will reduce the cost materially. So far as producing the minerals from greater depth is concerned it looks as though it can be done, and at costs that will not be prohibitive.

But that raises the questions as to whether the minerals exist at great depth, and; if they do, can we find them? We know very well, that some minerals do not exist at great depth; coal and petroleum do not go down any further than the sedimentary rocks extend, probably not more than twice as far as we have already penetrated. The minerals that occur in veins cannot go down indefinitely, for you eventually reach a zone of where the necessary fractures in the rocks cannot occur. There is no use dreaming of mine shafts hundreds

of miles deep, for there could not be mineral deposits at the bottom of them. But there are undoubtly deeper ones than those we have been mining.

Can we find them, however? Petroleum has been found at great depth by the study of geological stucture, but practictcally every deep mine is working on a deposit that has been followed down from the surface. The majority of mineral deposits do not extend continously to great depth, because their formation resulted from the presence of some particutar stratum, and when you pass out of it the deposit disappears. There are deposits that do not extend to the surface; some of them have been found by driving drifts and boring holes from the bottoms of mines, but the cost of this becomes high as soon as any considerable distances are involved.

In the past few years methods and devices have been invented for gaining information about the earth without making holes in it. We can find places that show unusual magnetic charateristics, electrical charactcristics, rate of transmission of shock waves, and those places that are light or heavy. These enable us to restrict our digging and boring to the most promising places, so we may be able to have a fair percentage of success in finding deep deposits. But when all is said and done it seems inevitable that the relative price of most minerals must advance in the future, because, they will be scarcer and more costly to obtain than they have been in modern times.

There seems to me no probability that our rate of consumption of minerals will go on accelerating as it has in modern times, except perhaps for a few, and for them not indefinitely. We seem to have lived in a period of rapid development that has largely spent its force. But perhaps I am wrong, for many times before people have supposed that no further progress was possible. Unless the rate does decrease it is certainly going to be increasingly difficult to find the minerals that will furnish greater incentive for the exercise of ingenuity by mining engineers and metallutgists, so there will be plenty of work for them to do.

III. China's Place in the Mineral World.

In an earlier lecture I have pointed out that China, up to the time of the Mongol invasion in the 13th Century, was probably the most advanced mineral-

using country of the world. It was employing techniques that no other people had, and it probably used more varieties of mineral and more mineral per capita than any other people. Soon after that a tremendous advance began in Europe, but not in China, which at the middle of the 19th Century was just where it had been at the beginning of the 13th. At that time nobody, neither the Chinese nor anybody else, knew very much about the mineral resources and possibilities of China.

But in the last 75 years a great change has taken place. In the meanwhlie a great deal has been learned about the mineral resources of China and there is now at Nanking a Geological Survey, with a large and competent staff, adequate buildings, and excellent equipment that is daily adding to that knowlege. But the most important thing is that the attitude of the people has changed, they now wish to alter their ancient ways of living so as to utilize minerals to improve the conditions of their existence, as is done in the Western world. That wish immediately raises the question as to whether China has sufficient supplies of the different minerals to permit it to be done.

At first no uneasiness was felt on that score. The first geological work done in China called attention to the enormous coal resources of Shansi and the flourishing iron industry there, with the result that the whole world came to think that China was a country of enormous mineral resources that were simply waiting to be developed. Later more careful work revealed that the iron ores there, though adequate for the native way of working, could never be made the basis of any extensive modern iron industry, and it eventually proved that even the coal resources of that region had been over-estimated. The general tendency now is to think of China as a country that is rather poor in mineral resources. It is my purpose to examine into that idea in detail, and consider how far it is justified.

As to coal, though the resources of Shansi are smaller than they were first supposed to be, they are still very large, and on the other hand, Shensi proves to have much more than was supposed. The southern part of China, at first thought to be rather unpromising, is revealing more and more widely scattered coal areas than were expected from it. It is quite true that mining conditions in China are less favorable than in the U. S., but there they are unusually favor-

able, and there is nothing impossible about Chinese conditions. It is quite difficult to produce a large proportion of lump coal from Chinese mines, and under present trade conditions it is difficult to sell the fine coal, but the use of powdered coal in large installations is already well developed abroad, and the aversion to the use of slack coal for that purpose is not due to its size, but its higher ash content; a condition that may be remedied by washing. The costs of coal mining in China are generally comparable with those in the United States, while the price of coal delivered at the large centers of consumption tends to be lower than with us. We may say of coal therefore that China has plenty to permit it to a advance far along the road of supplementing men's efforts with mechanical power, and so far as it is possible to see into the future we need not worry about that.

The other great mineral fuel, petroleum, is in quite a different situation. The present production in China is negligible, and all the geological studies so far made to find sources of large production have resulted only in failure. No one can surely say that petroleum in large amounts will never be found in China, But it is quite clear that there are large areas that cannot possibly contatin petroleum, and in those where the possibility is still open a number of geological conditions, that it would take too much time to set forth in detail, make the outlook very discouraging. The possible areas are in the far west of China, where transportation difficulties would be added to those of production, while present consumption are on or near the seaboard.

On the other hand, transportation facilities into the western areas are rapidly and steadily improving. And throughout the western world everyone has long been asking what we shall do when the present resources of petroleum, that are generally believed to be quite small compared to the present rate of production, are exhausted. Various things have been suggested, and two at least are of a great deal of promise. One of them is to produce petroleum products from the chemical treatment of coal. It is perfectly possible to do it, and an important fraction of the requirements of Germany are already being produced in that way. The one trouble is that it costs too much;— gasoline from petroleum is cheaper. When petroleum gets so scarce that gasoline made from it costs as much as that made from coal that condition will automatically correct itself, and China can

make its petroleum products at home as cheaply as it can buy them from abroad. At the present moment, if petroleum is left out, China's mineral exports somewhat exceed in value its imports, so far as figures are available. (they are somewhat misleading, for manufactured articles imported, though chiefly composed of steel and other metals, do not show in the figures as mineral imports). If the time comes when China can produce its petroleum requirements at home it is not likely to be a large importer of minerals.

The other possibility is to use alcohol as a fuel for internal combustion engines either alone or mixed with gasoline. Here again cost is the main factor; minor technical difficulties can be taken care of. And, as indicated above, cost will in time take care of itself. The great advantage of this solution is that the alcohol will be produced from straw and other vegetable by-products that are annual crops from the soil, and consequently available in never-ending supply. In China at the present time such material is to a large extent being used as fuel. When, through better transportation and distribution systems, coal becomes everywhere available, and a higher economic level of the people makes it less worth while for them to spend their time in gathering and handling such material, it will tend to become available for alcohol manufacture, and thus will fit in with the logical development of Chinese economy.

Iron is the next great problem. In the reaction from the earlier erroneous belief that China was extremely rich in iron resources, we have perhaps gone too far and tend to be too pessimistic about the situation. But in the light of our present knowlege it seems certainly true that China does not possess the large and rich iron ore deposits that are found in some other parts of the world. It seems to have rather a considerable number of rather widely distributed deposits of only modest size and in many instances of a quality that makes them rather unattractive as sources of iron so long as plenty of rich ore is still available. The problem is complicated by the aims of a neighboring power has, in one way or another, acquired control of the iron deposits of China's northern territories, but even with that the situation is by no means desperate. In order to make that clear I shall have to discuss the iron industry in some detail.

Technologists are likely to talk as though the possibility of developing an iron industry in a country depended simply on the presence there of large enough iron

ore deposits of good enough quality and a supply of coking coal. But the problem is more complicated than that. Without them you can have no production of raw iron, of course. If you have them and can raise the capital you can build a steel plant and proceed to produce billets, sheets, plates, etc., and then you find your real problem is to sell what you have produced. In the old producing regions there have developed through the years a host of intermediate plants that take these products and turn them into the thousand and one finished products which the consumer buys. In Kwangtung, for example, you not only do not have a steel-making plant, you do not have all these intermediate plants for turning the steel plant products into finished articles of commerce, and the thousands of little iron-working shops to be seen in the streets will be of no aid in meeting this situation. The large markets are largely closed to you: if you raise the capital for building a railroad abroad you usually have to agree to buy the rails and equipment in the country that supplies the capital. Steel for building construction, etc. is mostly used only in the coast cities where cheap ocean freights make it possible for big foreign producers, with their low costs due to mass production, to make a price that a domestic plant could not meet. An order for 100 tons of steel of a specified quality and size could probable be supplied by a big plant out of stock,—a small one might have to partly rebuild its plant to make it. It is difficulties such as these that help to make the growth of an iron industry in China slow.

On the other hand there seem to be not a few iron ore deposits in China that contain say, 10,000,000 tons, and while the supply of coking coal in many places presents the dilemma of chosing between a nearby supply of rather inferior quality or using better coke at the higher price resulting from its being brought from a distance, it still seems quite possible that China will in time be producing at home at least some considerable part of the raw iron that will be necessary for its industrial development. Such plants are not likely to be very profitable, especially at first, and it wil be necessary to aid them through subsidies and tariff protection, in the interests of balanced economy.

There is another factor that needs mention,—the increasing tendency for using metals over and over. There are some uses of metals, such as that of lead and zinc in paint, where it is not practicable to recover them when they have served

their purpose. But when lead is used to make a storage battery, it is all still there when that battery is worn out, and it is commercially possible to make a new battery out of it. Iron and copper are the two metals that are most reused; in the case of copper because its price makes it more worth while, and in the case of iron because it is so easy. More than half the steel made in the United States each year is made from old material, not new iron; it is possible to make it wholly of old, though not so easy. As soon as a country has a large amount of iron in use there is a constant stream of broken, worn, or obsolete, material being taken out of service and normally finding its way back to the furnaces for melting and re-fabrication. The question has even been raised by some, including myself, as to whether the strong tendency toward the use of lighter designs and stronger materials, as exemplified by the alloy steels, may not eventually bring us to a point where we shall need little or no new iron, but simply keep on using that which we have. We are still a long way from that point, but it seems to me we must inevitably reach it if we suceed (as we seem likely to do) in our attempts to stop the constant loss of iron through corrosion.

These facts, plus what I have said about the possibility of China producing iron in appreciable quantities, make me far from pessimistic about the development in China of those industries that involve the use of iron. So far as I can see there are enough iron resources in the world for everybody, and the present insane outbreak of nationalism, in which every country is seeking to produce within its borders everything it uses, will in time spend itself. It will then again be clear that the problem of unemployment is merely of bad management; the people of any country can all keep busy in making what they want, and if they have special advantages in the making of certain things they should make enough of those to trade for the things which they can produce only with difficulty, though they are easily and cheaply made elsewhere. China needs to increase its per capita production, but not necessarily of everything. Those things which are easiest and cheapest produced abroad it may properly continue to import. Whether it will ever come to the point where it will not need to import iron and steel in manufactured form, I do not know nor do I think it much matters.

Copper, lead and zinc may well be lumped together, since all three are in

the same situation. China, so far as we know, lacks large and rich deposits of them, though it produces a little of all three. What I have just said about iron applies here. The road from a lump of copper ore to a wire-wound electric generator is a long one and that part of it which extends from the copper ingot to the finished product is just as open to China as to any other country, since the differnce between the price of the copper involved as delivered in China or in Pittsburgh is an insignificant fraction of the price per pound of the finished product. If a country can develope a textile industry based on the import of so bulky a raw material as cotton no other field of manufacturing should be closed to it. From the mineral strategic viewpoint it would be desirable for China to have domestic supplies of these metals, but I cannot see that it matters much from the economic viewpoint.

Silver is a good example of what I mean. It has been extremely important to the conduct of business in China for centuries, but it has never been derived from deposits within China'a borders. If China has suffered any definite handicap because of that lack I am unfamiliar with what it has been. It might be argued that if China had not needed to buy silver through the export of commodities it could have bought other things, but that brings us back to the argument as to whether the people who produced the things that were exported could have been more easily and profitably employed in the production of silver, and that would lead us too far afield. Silver illustrates another important factor that applies in a lesser degree perhaps, to every other mineral. In the past year it has been found perfectly possible for China to get along without it, paper money having taken its place. Nearly all the minerals are competitive with each other for the privilege of serving man, and no one can possibly prophesy that we shall indefinitly continue to need them. Flint was once the most important mineral in the world, now we do not use it at all except to a limited extent as the pebbles in grinding mills, and even for that function iron balls and bars often serve better.

On the positive side China is the most important producer in the world of two minerals, antimony and tungsten. Unfortunately the world does not require large amounts of either one of them, so they do not produce large trade balances as exports. Tungsten has its market threatened by molybdenum, and almost every

use for antimony finds it in competition with some other mineral that is a possible substitute. China produces more tin than it needs, but these three metals and coal about exhaust the list of those minerals that it possesses in sufficient amount to warrant export.

So far I have said nothing about the non-metallic minerals, other than coal and petroleum. There is a long list of others, of which stone and clay are the first to come to mind. China has ample supplies of these and has always used them freely. What the situation is as to most of the others we do not know beyond that all of them so far required have been available. What demands will develope in the future, and how much will be available to meet them it would be useless to guess. Limestone is certainly available to meet any probable requirement, as are the special varieties needed for cement manufacture, which has already developed to an impressive extent in China. Magnesite, asbestos, talc, mica, and a host of others can probably be produced in larger amounts when and if needed. Salt is of course an old article of commerce in China; one that will be needed in increasing amounts as chemical manufactures develope. The sea's supply is unlimited and deeper drilling in Ssuchuan will probably yield increased amounts there.

It seems proper to conclude with the fertilizer minerals, since the increase of agricultural production seems the most important economic problem of China today. Probably 80% of her people are engaged in agriculture and to increase the prosperity of this large majority is the most certain way to raise the general economic level. Of this complicated problem, involving the use of improved seed, varieties better suited to the climate and the soil, farming in larger units, the substitution of power for human effort, and many other factors, only one, the use of mineral fertilizers to increase the yield, concerns us here.

No deposits of nitrates are known in China, but that is not unusual, since they do not occur anywhere in important amounts except in Chile. The other countries have remedied their lack by producing nitrates synthetically; a plant is already under construction at Pukow and others can be built as the demand developes. Phosphate is a different matter, it has to be mined. So far no deposits of importance have been found in China, but that should not be too discouraging as the huge deposits of the United Stat went unrecognized for many years. The

islands of the South Seas are fairly rich in phosphates and material from there can probably be delivered at the principal distributing centers as it could be from points within China. Potash has a less favorable outlook, since neither any deposits within China, nor any at all nearby are known to exist. Possibly the arid regions of west China will eventually be productive of it, but there the transportation difficulty again enters. Transportation costs will indeed be the largest factor in the use of mineral fertilizers. They must be brought down to permit the material to reach the farmer at a price that will yield him a profit through its use, and also to enable him to market his increased yield through reaching more distant markets.

The conclusion of our review is that although China is, except for coal and a few of the orther non-metallics, by no means rich in minerals, and is even decidedly lacking in some, the outlook is not one of economic discouragement. The increased use of mineral substances in China to improve the condition of her people is a complicated problem that is quite as much a matter of business organization as it is of technology, and one that will have to be worked out gradually. Her abundant supply of caol gives her the principal basis of industrial development, and there seems no reason why general manufacturing cannot develope on the basis of imported raw materials here, as it has had to elsewhere. The greatest asset of any country is a progressive, wide-awake people with a will to succeed. There is an old adage which says "Where there is a will there is a way".